Simulation Modelling Practice and Theory 48 (2014) 58–92

Contents lists available at ScienceDirect

Simulation Modelling Practice and Theory

journal homepage: www.elsevier.com/locate/simpat

A verifiable simulation model for real-world microscopic traffic simulations

J. Brügmann [a,*,1], M. Schreckenberg [a], W. Luther [b]

[a] Department of Physics, University of Duisburg-Essen, Duisburg, Germany
[b] Department of Computer Science and Applied Cognitive Science, University of Duisburg-Essen, Duisburg, Germany

ARTICLE INFO

Article history:
Received 8 February 2014
Received in revised form 21 June 2014
Accepted 8 July 2014
Available online xxxx

Keywords:
Simulation model
Microscopic traffic simulation
Executable formal semantics
Verification and validation

ABSTRACT

This article presents a scientific discussion about the ongoing progress in the development of traffic simulation system platforms. As part of the discussion, the presentation introduces a simulation model that is based on the fully functional, real-world online traffic information system OLSIMv4 which is the updated version of the traffic information platform for the highway network of North Rhine-Westphalia (Germany). The simulation model consists of a simulation engine and a combination of several subject-specific model families such as vehicle models, microscopic traffic models, detector models, and tuning element models. Additionally, it provides a data model for arbitrary road traffic networks in highway and urban environments.

The presentation includes a demonstration of how to form and initialize all relevant system components by providing an example for each component. The demonstrations use the declarative programming language Maude to form and initialize the components due to its simplicity and expressive power. The components facilitate their enhancement by a verification and validation management approach. The goal of the enhancement effort is to optimize the further development of the underlying OLSIMv4 system. In addition, the presented methodology stands exemplarily for the design and implementation of a whole class of systems. Additionally, the definitions of the simulation model can be used as a specification for an implementation with sequential, parallel, and distributed operation. Therein, independent entities can be inferred automatically by the simulation engine as part of an automatic domain decomposition. It has been implemented as a sequential and a parallel simulation that exploits CPU thread-level parallelism.

1. Introduction

Microscopic traffic simulations use individual vehicles that move according to the rules of a microscopic traffic model in a virtual road traffic network to obtain traffic information. As an example, typical traffic information determined by a simulation is depicted in Fig. 1. Therein, the "global" labelled line represents the density optimized, spatio-temporal traffic information. The online traffic information system OLSIMv4 has been described in our previous publication [1]. It has derived the traffic information from flow optimized, stationary traffic data provided by loop detectors that is represented by the

* Corresponding author. Tel.: +49 162 9149048.
E-mail addresses: johannes.bruegmann@uni-due.de (J. Brügmann), michael.schreckenberg@uni-due.de (M. Schreckenberg), luther@inf.uni-due.de (W. Luther).
[1] Principal corresponding author.

http://dx.doi.org/10.1016/j.simpat.2014.07.002
1569-190X/

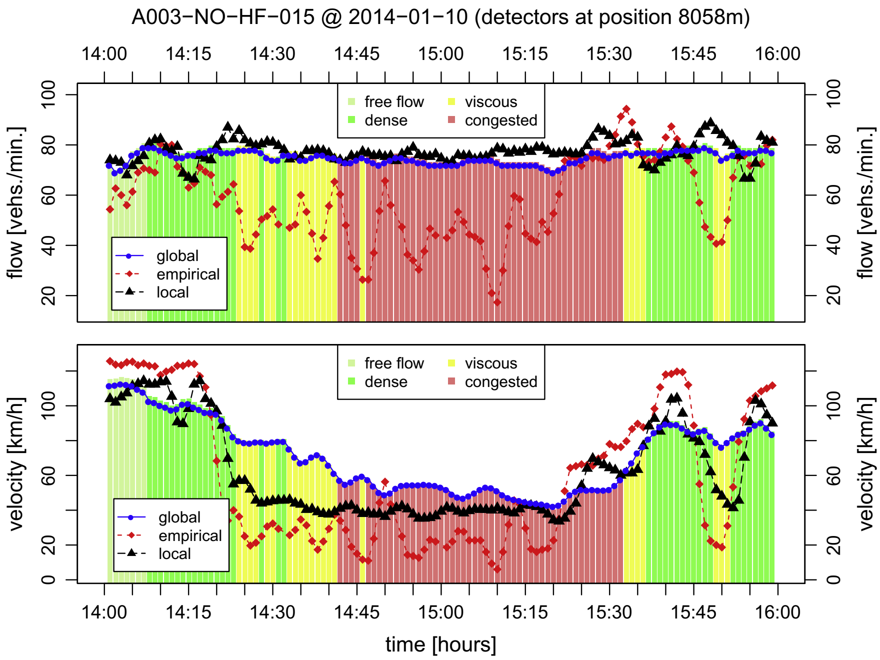

Fig. 1. Spatio-temporal traffic information ("global" labelled line) derived from stationary traffic data provided by loop detectors ("empirical" labelled line) for the 8 km long A3 section between Breitscheid and Duisburg-Wedau on Friday 2014-01-10. The "local" labelled line displays stationary data obtained from the simulation with a method that emulates the behaviour of the loop detectors.

"empirical" line. The bars under the "global" labelled line represent the level-of-service for the particular road segment. The level-of-service indicates free flow, dense, viscous, or congested traffic to the user. The velocity, as depicted by the "global" labelled line in the bottom row plot, forms the basis to calculate more meaningful, spatio-temporal traffic information for the road segment such as travel times. The "local" labelled lines in both plots represent stationary traffic data obtained by the simulation with a numerical method that corresponds to the behaviour of the loop detectors.

Microscopic traffic simulations participate in multiple contexts and for varying purposes – to improve traffic network performance and to assist the infrastructure planner, or to assist drivers in route planning, in context of urban environments, or to simulate highway traffic flow. Microscopic traffic models describe vehicle motion as the result of a vehicle's interaction with other vehicles and with road infrastructure interaction according to the traffic rules. In addition to microscopic traffic models, a simulation system also involves a number of other model families. Among them are the vehicle models, the network models, the detector models, the accumulator models, the tuning element models, the traffic light models, and the control models. Typically, microscopic traffic simulations have to support many vehicular traffic environments and they have to simulate on a lot of varying road geometries. They have to support a broad spectrum of data sources, run on large networks exploiting hardware parallelism, and finally should grant correctness of the results. Besides the complexity of the involved models, the difficulty of implementing a microscopic traffic simulation is beyond the complexity of the various involved models for the following reasons.

First, there is no microscopic traffic model that fits all needs for the various kinds of vehicular traffic flow. Highway traffic, urban traffic with lane discipline, traffic without lane discipline, or simply scientific traffic evaluation are kinds of vehicular traffic. Moreover, a microscopic traffic simulation may not be limited to vehicular traffic. It may include molecular transport, packet transport, rail, and pedestrian traffic. Thus, microscopic traffic simulation systems have to provide several traffic models among which an implementer of a simulation system can choose from for any set of roads. As the traffic model has to apply the traffic rules of the road environments, i.e. speed limits, traffic lights, variable message signs, overtaking restrictions, lane closings or merges, it has to be aware of some kind of topology. Moreover, in some scenarios it may be even necessary to take intersection topologies, ascending or descending road slopes, arc radius, and visibility headway into account. These dependencies limit the traffic model's portability and make it hard to develop a simulation system model for a variety of potential application domains.

Second, information accuracy, increasing network size, network independency, and system scalability are conflicting goals. In general, and for larger networks in particular, a simulation system can take over data from a lot of different data sources that have the potential to increase information accuracy. For example, the data sources may include loop detector data, camera detector data, traffic light states, variable message sign states, static signs, road restrictions, floating car data, weather data, and toll station systems data. On the one hand, while processing more data does not lead automatically to improved information accuracy, most data has the potential to do so. On the other hand, processing more data requires more